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DEVELOPING A 3D PRINTED PATIENT-SPECIFIC CAST FOR A FRACTURED WRIST FROM CT SCAN DATA

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ABSTRACT

Hand fractures are a common cause of injury for the athletic and general population. However, it has been observed in several instances that, the traditional plaster casts are responsible for causing skin and soft tissue infection. The conventional plasters are itchy, uncomfortable and are considered to be ineffective heat repellents. Thus, the need of the hour today is, to overcome these limitations by providing an alternate solution for the masses, which is deemed acceptable as per the medical standards. A 3-D printed cast made out of Poly-lactic acid (PLA), which is manufactured using the Material extrusion technique, is the plausible solution. This paper provides a methodology to design the cast using the patient's distinctive geometric features. The aforesaid cast has been modelled using the specific hand geometry, which was obtained from that particular patient's CT- Scan data using open-source software. The objective behind using the 3-D printing technique is to develop a precise final product, which is patient-friendly and light-weight. The entire process revolves around the 'best fit geometry'. This paper aims to find an accurate, quick and effective 3-D printed cast solution.

KEYWORDS: CT-Scan; DICOM File; Poly-Lactic Acid; Material Extrusion & 3-D Printing

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Original Article

1. INTRODUCTION

It is a well-known and widely understood fact that bones are the most rigid structures in the human body. These play an important role in supporting various vital organs in the body and even help in the production of the Red and White Blood Cells. Bones are a storehouse of minerals, which are extremely essential for the wellbeing of the body and its proper functioning.[1] In case of an accident, the injured bone may change its alignment or may get shattered into pieces, moreover, there is a possibility that a bone fragment breaks through the skin causing infection, wherein, the affected hand begins to show signs of swelling, on getting fractured.

The current method of bone stabilisation involves the use of Plaster of Paris (POP) and fibreglass, but it suffers from several disadvantages like lack of scope for heat dissipation and air circulation, lack of water resistance and is even prone to skin infections. The finest solution presented in the form of the '3-D printed cast', eliminates all these shortcomings by providing effective results and an excellent fit, for the respective patient, because it is custom made. The 3-D printed cast is designed and manufactured layer by layer in such a manner that it has a sufficient amount of cohesive forces to provide the necessary strength to the affected hand.[2]

The methodology involves the usage of a CT-Scan, which gathers the specifications of the broken hand, and various open-source software's which are used to build the personalised cast.[3] This cast allows the patient to bathe conveniently, without worrying that it may get wet. The printer prints the cast in two parts. Zip ties are used

to secure the parts to the hand. The patterns on the cast aid the doctor in analysing the condition of the arm.

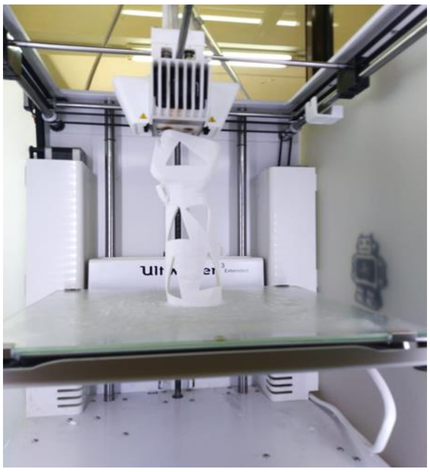

Figure 1:Printing of the Cast using Material Extrusion Technology.

The openings/patterns on the cast provide a significant advantage to the doctors for a convenient examination of the patient's condition. The doctor has the option of efficiently stimulating the bones with ultrasound, which can help the bones heal faster. This cast also allows the patient to bathe without using any external protection or cover for the cast. The cast is created using the geometric reference of the 3-D model, which makes it a custom fit for the respective patient. The cast manufactured by Material extrusion method of 3-D printing has a thickness of 5 mm.

2. LITERATURE REVIEW

A hand fracture is a typical cause of injury among the masses of India. 2.4% out of 100 people suffer from one or more fractures during their average lifetime. POP casts are not hygienic, and the skin requires post medication after removal of the cast. The purpose of this project is to find an alternative hygienic solution by smart modelling technique produced by 3-D printing technologies.[4,5]

High impact accidents or bone diseases cause maximum bone fractures. Usually, Plaster of Paris (POP) or fibreglass are used in accordance with the geometry of the body. The first process in constructing a cast is to clean the skin with ointment. Then a cotton padding is induced for comfort. The next step is to place plaster sheets over the hand after dipping into lukewarm water. The plaster is moulded over the hand and its contours to give it a proper shape. The cast is non-removable and unventilated. These casts suffer from side effects and in many cases, they are even responsible for causing several skin diseases.

Figure 2: Application of 3D Printed Cast.

Thus to overcome these problems, there was a need to come up with newer technologies and materials. 3-D printed plastic material is light in weight and offers the same strength as a traditional cast.

In material extrusion, the melted material is deposited layer by layer. The material used, is in a filament form. The first step is to load a spool of the filament into the printer. The melted material is processed in a manner that it gets ejected out in the form of thin strands from the head and is deposited layer by layer at predetermined locations, where it solidifies. Multiple passes are made to fill the area; the built plate moves down as one layer is formed.[6,7] This process is repeated until the entire model is complete.

Current trends emphasise the use of biodegradable plastic. Therefore, PLA (polylactic acid) is selected for the process.[8] The main advantage of this material is that it is an environment-friendly (biodegradable) thermoplastic, made up of corn starch and sugarcane, which are renewable. PLA is resistant to warping, and it prints even in the absence of a heated bed.[9] The post-processing of PLA is very easy; it requires only sanding. The process of biodegradation is dependent on environmental conditions. For visible degradation, it takes one year.

Figure 3: Standard Sizes of the Cast.

The current situation in the Indian market doesn't make it feasible to manufacture custom 3-D printed casts for individual patients.[8] Since 85% of the population belongs to the lower-middle-income class or the weaker sections of the society, thus, it is not very viable due to its high cost, making it unaffordable for a lot of people. But mass production of these casts in 3 basic sizes can make them cost-effective and affordable to a large extent.[10] This cast can be designed in a manner that fits the patient, although with minor adjustments, which can be made during the application, since every hand has similar geometric shapes but different dimensions.

3. METHODOLOGY

This paper aims to develop a methodology which can be used to create a 3D printed cast from CT-Scan data.

1. Procurement of DICOM file
↓
2. Conversion of DICOM file into 3D Model
↓
3. Extruding the model in Autodesk Netfabb
↓
4. Creating a shell on the extruded model to make the cast
↓
5. Creating patterns on the model using Netfabb for ventilation
↓
6. Printing the Model on 3D printing machine
↓
7. Post-processing of the printed model

Figure 4: Steps to Create the 3D Printed Cast.

3.1 Converting DICOM File into 3D Model using Slicer 3D Software

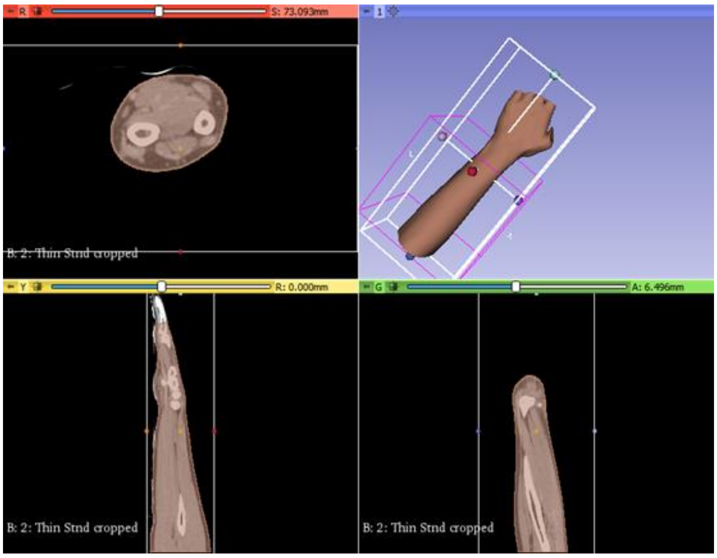

Figure 5: 3-D Model of the Hand from DICOM Data.

The entire model is developed with the use of open-source software. DICOM (Digital Imaging and Communications in Medicine) file of the hand is obtained by performing a CT-Scan, which uses a combination of X-ray measurements at various angles to produce slices of the images at three planes. The DICOM file generates the images of the hands in layers, as per the medical standards. The first step is to load the DICOM file on the Slicer 3-D software. The 2-D images are cropped according to the required area of interest. The software allows the user to crop the images by interpolated cropping or voxel-based cropping method. The next step is to convert the images into a 3D model using the segmentation editor. [3] The 3-D model created is shown on the right-hand side in figure 6. The final model is saved in the STL file format. The outer surface of the model is generated in the form of triangles without any information regarding colour, texture, or other attributes. The final model has a large number of triangles; these can be reduced for the ease of further operations by making use of the decimation function. The cast is then created, based on the geometric reference of the 3-D model created in Slicer 3-D.

3.2 Use of Autodesk Netfabb for Extruding the 3-D Model

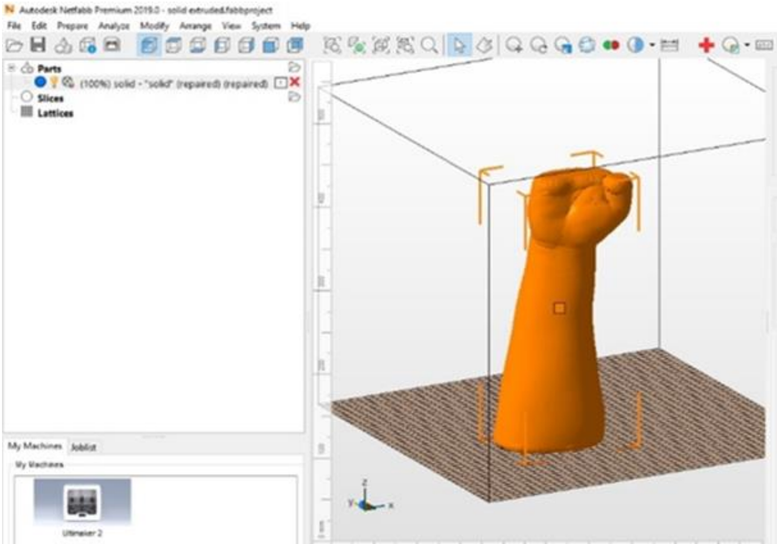

Figure 6: Extruding the Model using Autodesk Netfabb.

The drawback is that the model saved in the form of STL has errors. When the triangles are reduced, many triangles combine to form a bigger single triangle. Thus, an overlapping error occurs. Some curved surfaces are represented as a flat surface which creates a void. Due to this, closed geometry is not achieved, which is also a form of error.[11] These errors are repaired using ‘Autodesk Netfabb’. The ‘repair part’ function is used to check the orientation and closed structure of the mesh. Repair scripts are run under the ‘action’ section in order to repair the errors. The repaired model is then saved and all the triangles are extruded to 6 mm. The extruded model is finally saved for creating a shell.

3.3 Creating a Shell to Make a Cast

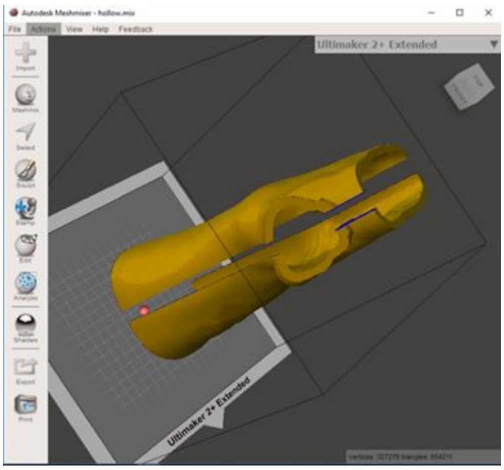

Figure 7: Sliced Model.

The extruded model is made hollow such that it fits like a shell around the hand. The hollow function in Autodesk Meshmixer allows the user to select the offset distance as well as to optimize the mesh density. The model is made hollow, keeping an offset of 5 mm from the outermost surface. This model is then saved, and sliced into two parts for the purpose of convenient fitting and removal from the injured hand. The ‘plan cut’ function in Meshmixer is used to cut the model into

two parts. The merit of using Meshmixer is that it can store the previously made models as primitives, and these primitives can be attached to the model using Boolean operations. The protrusion for accommodating the Zip ties are added to the sliced model at determined positions such that the zip ties pass through the openings on both the sliced parts without any obstruction. The protrusion is created using ‘Solidworks’, which is finally added in the Meshmixer software as a primitive.

3.4 Creating Patterns on the Model using Netfabb

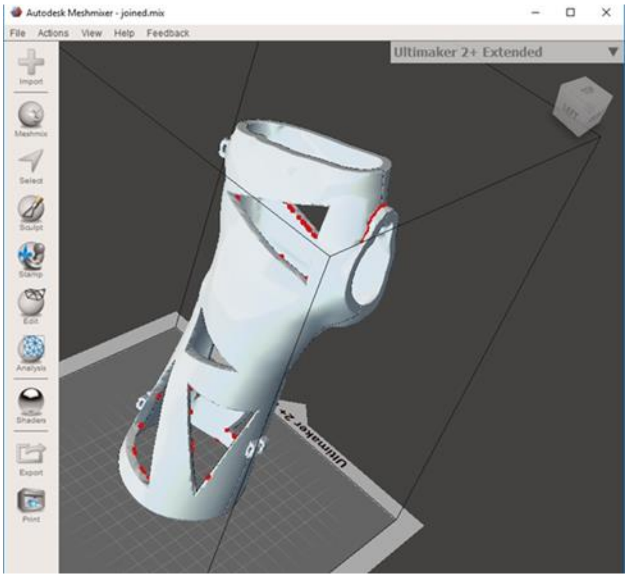

Figure 8: Cast with Openings.

Autodesk Meshmixer is used to create triangular patterns in the model, as shown in figure 8. The reason behind selecting triangular patterns for the model is that their designing and creation on the 3D printing machine is comparatively easier. Triangle lines made at an angle of 20˚ do not require any support material. This ensures that the triangle doesn’t have any overhangs while creating the patterns. The triangles also reduce the mass of the overall model, which gives the cast an added advantage of being light in weight.[12] The ‘free cut’ function allows the user to cut or amend the model according to the polygon shapes. While using this function, the original part is re-meshed after the polygons are cut.

3.5 Printing the Model on 3-D Printing Machine

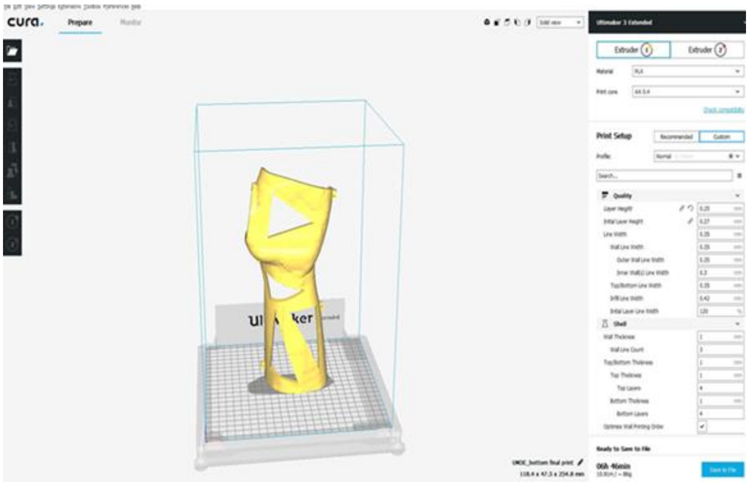

Figure 9: G-Code Format in Ultimaker Cura.

The STL file with the created patterns is converted into the ‘G code’ format with the help of ‘Ultimaker Cura’. The suitable material (discussed earlier) is selected for printing, and the printer configuration in terms of layer height, temperature, infill percentage, and type of infill is setup. The file with all these settings is thus saved in the G code format. The G code file is then supplied to the printer for printing.[13]

3.6 Post-Processing of the Printed Model to Derive a Better Surface Finishing

Figure 10: Post Processing of the Cast.

After the printing process is complete, the cast is polished with sandpaper in order to get a smooth surface finish. The occurrence of any distortions while printing can be fixed/rectified in this step. The cast is then spray painted, and a lacquer coat is added for protective coating.

4. ANALYSIS

The model of the cast is saved in the ‘Step file’ format. The step model is imported in ‘Ansys’ for analysing the stresses and to determine the strength of the cast. Several studies have been conducted on the human hand; it is ultimately understood that a human palm is capable of exerting a maximum of 30 psi of pressure. The pressure applied by the hand acts from the inside of the cast. The cast is a static member put on the hand. The model is then prepared for Ansys analysis by supporting it with material properties of PLA under the static structural section, which in turn is meshed using the automatic method, which created 179487 elements.

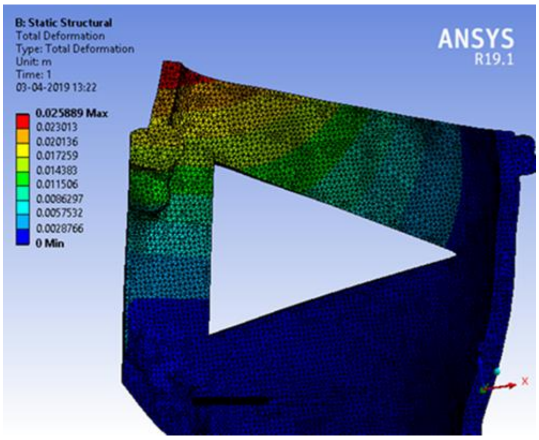

Figure 11: Analysis of the Cast in Ansys.

For performing the analysis, the section where the cast has provision for locking is given fixed support. The area of the palm which comes in contact with the cast is selected and 30 Psi of pressure is applied to the selected area.

5. RESULTS

The maximum deformation is observed at the edge where the locking provision is absent. Thus, this deformation is corrected with the help of Analysis function, which indicates the correct position of the locking mechanism. The maximum deformation came out to be 2.5 cm for a pressure of 30 Psi. This indicates that the necessity of placing the locking provision near the ends of the palm/ at the flanks of the palm.

Table 1: Stress Analysis Results

Stress Analysis Results		
Parameters	**Top Cast**	**Bottom Cast**
Total Deformation	0.025 m	0.033 m
Equivalent stresses (Von Misses)	1.56e8 Pa	1.07e8 Pa
Equivalent elastic strain	0.174	0.126

6. FUTURE SCOPE

With the development of 3-D printing technology, the time and cost of printing and performing the entire operation could be minimized. Also, with the introduction of newer materials in 3-D printing technology, better strength could be achieved.[14]

With further research, replacing the CT-Scans with X-ray scans could be made possible, for various profiles.[15] The scanning of an injured patient’s hand is cumbersome, so the designing of a fixture for the ease of scanning would prove to be highly beneficial.

7. CONCLUSIONS

The cast made up of PLA has a higher strength to weight ratio than the conventional plasters. The 3-D printed cast overcomes all the limitations of a conventional plaster. The use of custom data, for the purpose of manufacturing the 3-D printed casts, makes them an excellent fit with exquisite aesthetics. The cast is made up of PLA which is completely biodegradable and can even be reused, thus making it eco-friendly. The cast prepared in standard sizes can easily be made to fit the patient’s hand, with minor adjustments. The overall cost of the 3-D printed cast can be minimized by producing it in bulk, thus making it affordable for a significant section of society.

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